Structural and Geomorphological Evolution of the Area around Narella, Andhra Pradesh, India: A Study Based on Field Investigation, GIS and Remote Sensing

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Abstract

Eastern Dharwar Craton in Narella area of Karimnagar district (India) is studied using GIS, remote sensing and planar fabric preserved in high grade metamorphic rocks and structural deformation in their associated igneous dykes and supracrustals. Two distinct phases of deformation characterized with F1 and F2 plunging folds have given rise to ENE-WSW and NNW-SSE aligned ridge and valley system often dislocated by strike slip faults. Structurally controlled drainage, vertical scarps, shattered residual hillocks point to a rejuvenated topography undergoing slow and steady transformation under accumulating stresses in the area. Such tectonically controlled features demand for a reappraisal of seismic hazard zonation assessment in the area.

Keywords

Eastern Dharwar Craton; Remote Sensing; Structural Fabric; Geomorphology; Seismic Hazards; India

Introduction

The investigated area located around Narella in Karimnagar district, India covering more than 240 sq kms of Andhra Pradesh lies between 79˚E & 19˚'N to 79˚5'E & 18˚45' N (SOI toposheet no.56N/1). Narella lies at a distance of about 245 kilometers from Hyderabad and is well connected to nearby areas both by road and train routs (Fig. 1a, b). Narella area is predominantly a granite-gneiss terrain along with exposures of charnockite, banded magnetite, quartzite and dolerite dykes. The granite-gneisses and charnockites contain enclaves of high-grade supracrustals, including quartz-free sapphirine–spinel granulites, gneisses and basic granulites, which rarely occur in the entire northeastern portion of Eastern Dharwar Craton. Varieties of rocks from the study area reveal a wide range of mineral parageneses and these rocks have been investigated by different workers for mineralogical, pertological details and radiometric dating[1-7] (Fig.1c). Unfortunately however, metamorphic rock exposures in the area are scanty and normally found in the form of isolated hillocks or discrete blocks providing no opportunity for detailed structural and geomorphological analysis.

In recent years structural and geomorphological investigations using remote sensing and GIS have been attempted by many workers viz., Goswami and Yhokha[8], Singh and Srivastava[9], Prakash et al.[10-11] etc. Structural and GIS based geomorphological investigation in the Narella area has received no attention in the past and therefore in the present communication structural and geomorphological evolution supported by GIS and remote sensing in conjunction with field evidences around Narella area has been done. Such studies may be of help in reassessing seismic hazard zonations in otherwise stable cratonic areas of southern India. It is to be pointed out that, the study area located near Hyderabad classed under hazard zonation category II by the Bureau of Indian Standards, 2004, has been experiencing earthquake shocks with different magnitudes in the recent past[12-13].

Geological Setting

The Southern Granulite Terrane (SGT) is one of the largest exposed Precambrian deep continental crustal sections consisting of polydeformed Archaean and Proterozoic high-grade metamorphic and magmatic rocks. The two blocks of SGT (Northern and Southern), separated by Palghat-Cauvery Shear Zone (PCSZ) had been at the focus of the petrology community for several decades (Kelsey[14] and

references therein, Prakash et al.[15]). SGT is regarded as an ensemble of fragmented and imbricated crustal blocks separate by an E-W trending crustal-scale shear zone system consistent with late Neoproterozoic transpressional tectonics in a convergent regime[16-17]. The northern block of SGT lies between Moyar-Bhavani (MBSZ) and PCSZ. However, no conclusive information is available in the SGT about the precise demarcation of shear zones. The E-W trending PCSZ, first identified from LANDSAT shows the surface extent of the shear zone and proved that it is a crustal-scale shear zone. Seismic imaging and field observations[18] subsequently ratified a complex ductile nature of the shear zone. On the other hand, many workers have questioned pervasive shearing along the entire PCSZ[19].

The Dharwar Craton lying north of PCSZ consists of a NNW- and N-trending greenstone-granite belt surrounded by granite gneisses. It is divided into the Western Dharwar Craton (WDC) and Eastern Dharwar Craton (EDC), separated by a N–S-trending thrust located at about 25 km west of the N–S-trending arcuate Closepet Granite. The study area lies in the northeastern part of the Eastern Dharwar Craton, in the north of which lies the Permocarboniferous sedimentary formations of Godavari Graben (Fig. 1b).The Eastern Dharwar Craton displays a general increase of metamorphism from greenschist to granulite facies southwards in the central and southern part of the Craton. The radioactive mineral or whole rocks dates from the Eastern Dharwar Craton are meager or insufficient for understanding the structural and metamorphic evolution of the area in a precise time framework [2, 20].

Materials and methods

In the present study SOI toposheet no. 56N/1, has been used to digitize contour values, drainages and spot heights to generate DTM (Digital Terrain Model) of the area for structural and geomorphic analysis and drainage configuration using GIS software. The contour ranges from 180 to 500 feet at the interval of 20 feet. The spot heights given in toposheet have been digitized to create spot height point map. Extensive field work has been done to provide ground check validity to DTM, drainage patterns and to collect data for structural analysis (FIG. 2). DTM is useful tool to interpret the geomorphic and tectonic features of any area in conjunction with satellite data and ground trothing[10, 11]. Ordering of drainages has been done on the basis of Horton[21] (FIG. 3). Remote sensing data of Landsat thematic mapper (Landsat – TM of 11.05.2002; 1:50,000) has been used for delineating lineaments and structural features and their trends.

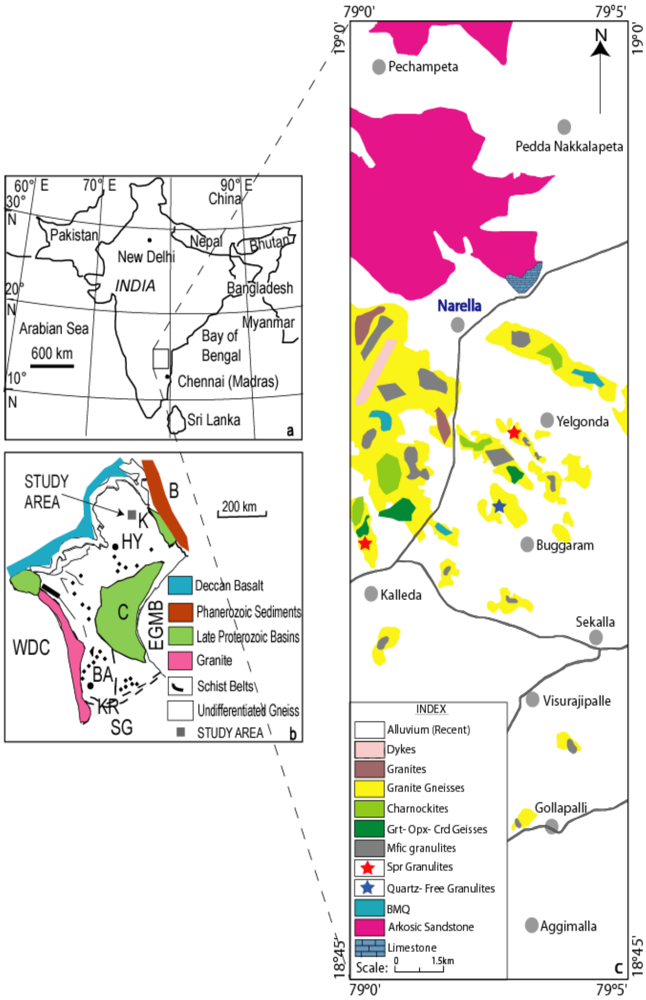

FIG. 1 (a) Reference map of India; (b) Lithological patterns for Precambrian rocks of the Eastern Dharwar Craton along with craton boundaries. The abbreviations used are: WDC – Western Dharwar Craton, SG – Southern Granulite, EGMB – Eastern Ghats Mobile Belt, B – Bastar Craton, Hy – Hyderabad, K – Karimnagar, C – Cuddapah, BA – Bangalore, KR – Krishnagiri; and (c) Geological map of the area around Narella.

Structural analyses

The metamorphosed rocks are present throughout the area from Narella to Raghavpatnam. The uppermost sedimentary cover in the study area has not been covered in the present structural analysis. For geometry and orientation of FIG. 1 macroscopic structures planar fabric data has been used. It has been noticed in the field that there is a general dominance of WSW-ESE strike trend in almost all the formations with significant variations at places. Dips of these formations vary in general from 25º to 65º. The banded magnetite quartzite and granite gneisses are traversed by numerous joints. Most of the joints are either vertical or steeply dipping.

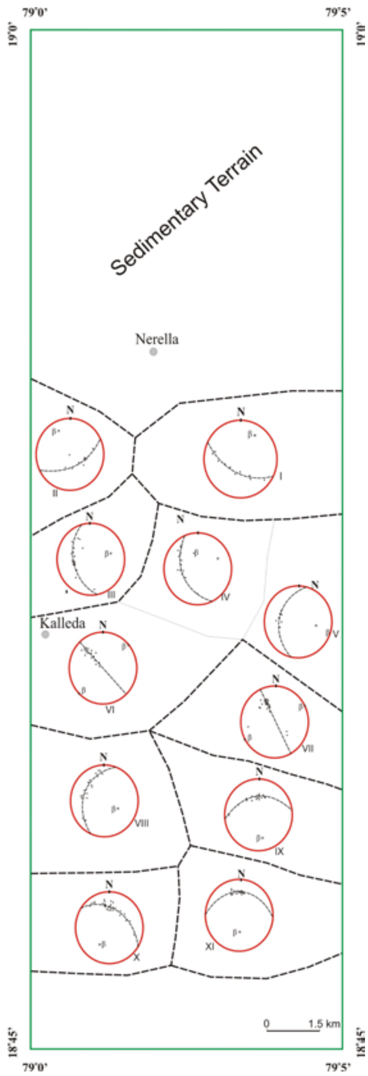

FIG. 2 π-s diagrams in different sub-areas around Narella

The outcrop pattern, development of folds and the general topography of the area suggest more than one phase of deformation complicating fold patterns on mesoscopic to macroscopic scale. The refolding of strata has rendered the area structurally heterogeneous with respect to both planar and linear fabric. The prominent S-surface denoted by foliation in different metamorphic rocks viz. granite gneiss, charnockites, garnet-cordierite gneiss, mafic granulites, sapphirine granulites etc. shows significant variations in structural trends throughout the area. Therefore, for structural analysis, it is rather difficult to divide the area into strictly homogeneous sub-areas. An attempt however has been made to divide the whole study area into eleven statistically homogeneous sub areas with respect to general orientation of dominant foliation. In each sub-areas, the orientation diagram of poles to S-surfaces was plotted on the lower hemisphere of equal area net. π-s girdle was drawn in each sub-area and the β-axis (poles to π-s girdle) was determined (Fig. 2). π-s diagram in each sub-area was drawn graphically by the method given by Turner and Weiss[22] and Billings[23]. The variation in the trend of β-axis in different sub areas suggests that the area under investigation has undergone repeated folding. Multiple phases of folding have also been reported by earlier workers from this part of the Precambrian Shield of south India[6-7]. Based on orientation of the β-axes in different sub areas, nature of fold patterns is described in the following paragraphs (Table 1).

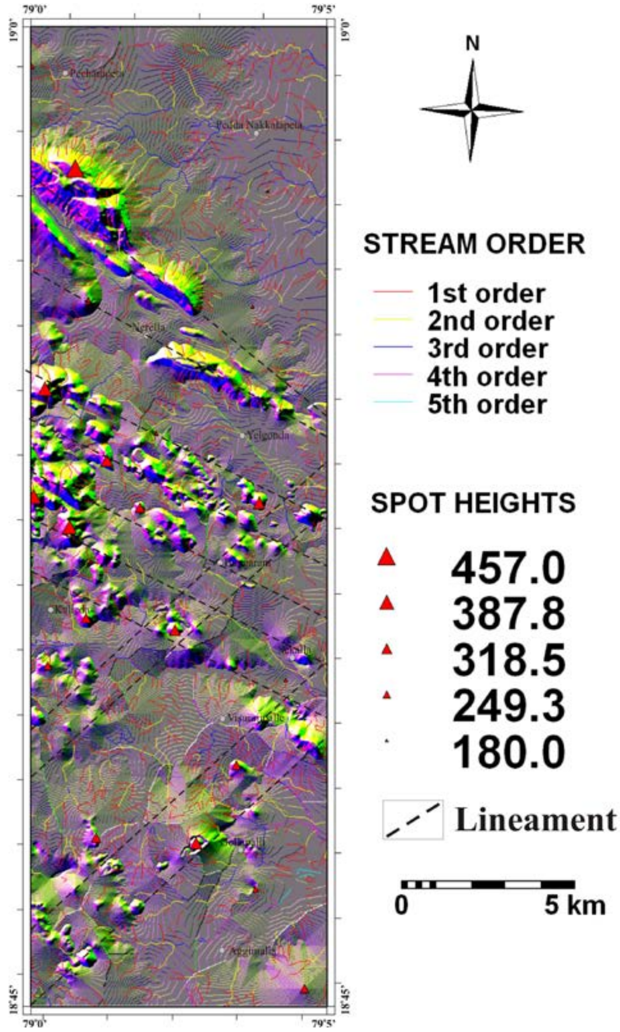

FIG. 3 Digital Terrain Model of the study area showing three dimensional synoptic views and two trends of lineaments resulted from different folding episodes

TABLE I Inferred orientation of β-axes in different sub-areas of the study area

Sub-areas	Plunge	Direction
I	30°	N 28° E
II	30°	N 28° W
III	40°	N 80° E
IV	36°	N 70° E
V	45°	S 68° E
VI	0°	NW-SE
VII	0°	N 28° W- S 28° E
VIII	50°	S 45° E
IX	40°	S10° E
X	54°	S 5° W
XI	42°	S 30° W

On the basis of data, analyzing two phases of folds on the macroscopic scale can be easily deciphered. The first phase of folding is represented by ENE-WSW trending axial plane. This phase of folding (F_1 folds) was subsequently subjected to the second phase of folding (F2 folds) on macroscopic scale. The axis of F_2 fold which runs approximately in NNW-SSE direction plunges towards northern direction which is represented by the β-axis in sub-area I and II in Fig. 2. Because of the second phase of folding, the axis of F1 folds has rotated form ENE-WSW to NNW-SSE direction paralleling with the F2 generation folding. The limbs of F1-folds were also rotated during the F_2-folding as a result of which the β-axis in the Kalleda and Buggaram area (sub areas III, IV and V in Fig. 2) plunges towards eastern direction. Further south near Rapalle area non plunging axial plane has been noticed trending in NW-SE direction (sub area VI and VII in Fig. 2). In contrast, in the southernmost side near Sriramulapalle and Gallapalli areas (sub-area VIII, IX, X and XI in Fig. 2) due to rotation, β-axis plunges towards the southern direction. Thus, from structural point of view, it appears that there is significant change in folding pattern throughout the area. This is in agreement with the regional geological setting as there is a profound swing in the trends of folding pattern in the Eastern Dharwar Craton.

An attempt has been made in the present work to validate the structural analysis finding with the GIS based DTM and remote sensing data in view of field evidences. The DTM of the area is shown in Fig. 3. The linear pattern of hills can easily be picked up near Narella area. Major lineaments present in the study area trending in the NNW-SSE and ENE-WSW direction are apparent; and the folding episodes may be related to activity along these lineaments (Fig. 3). Remote sensing data of the study area is also showing colour contrast arranged in linear pattern which is due to presence of scarps and mesoscopic folds developed during different tectonic episodes (Fig. 4). Synoptic field photograph showing linear arrangements of plunging anticlines and synclines near Narella (plunging in SW direction) is shown in Fig. 5d. Among mesoscopic evidences, tight isoclinal folds with curved axial plane (Fig. 5b, c) and inclusion of rolled garnet (Fig. 5a) have been found in the area around Kalleda which has undergone two subsequent phases of deformation.

Geomorphological Analysis

Morphological investigation of topographical features has long been applied in the structure and tectonic studies[24] because the manifestation of the sub-surface geology and structures are many a time, well documented in the landform features of a region[25].

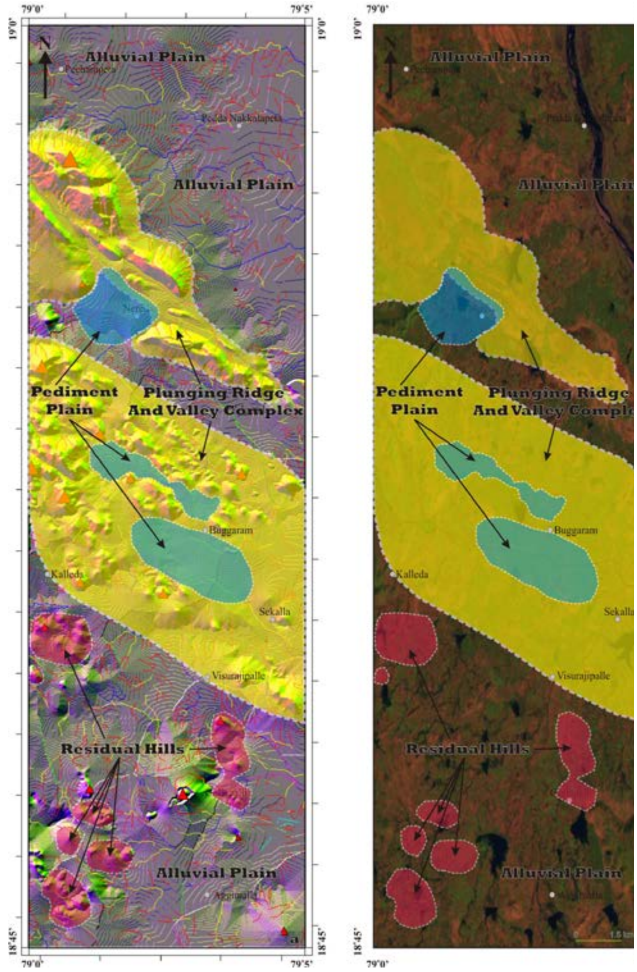

FIG. 4 Geomorphic features of the study area shown on, (a) Digital terrain Model and; (b) Remote sensing image

In the back drop of structural analysis DTM, remote sensing and detail field checks helped delineating important geomorphic features in the study area. The following geomorphic features have been deciphered and mapped in the present study (Fig. 4):

(1) Plunging ridge and valley complex,
(2) Alluvial plain,
(3) Pediment plain and
(4) Residual hills

The geomorphic features deciphered from field study and DTM analyses strongly validate remote sensing data. Plunging ridges and valleys are present roughly in NW-SE trend between Narella and Kalleda in the study area (Fig. 4a, 5d). Similar NW-SE

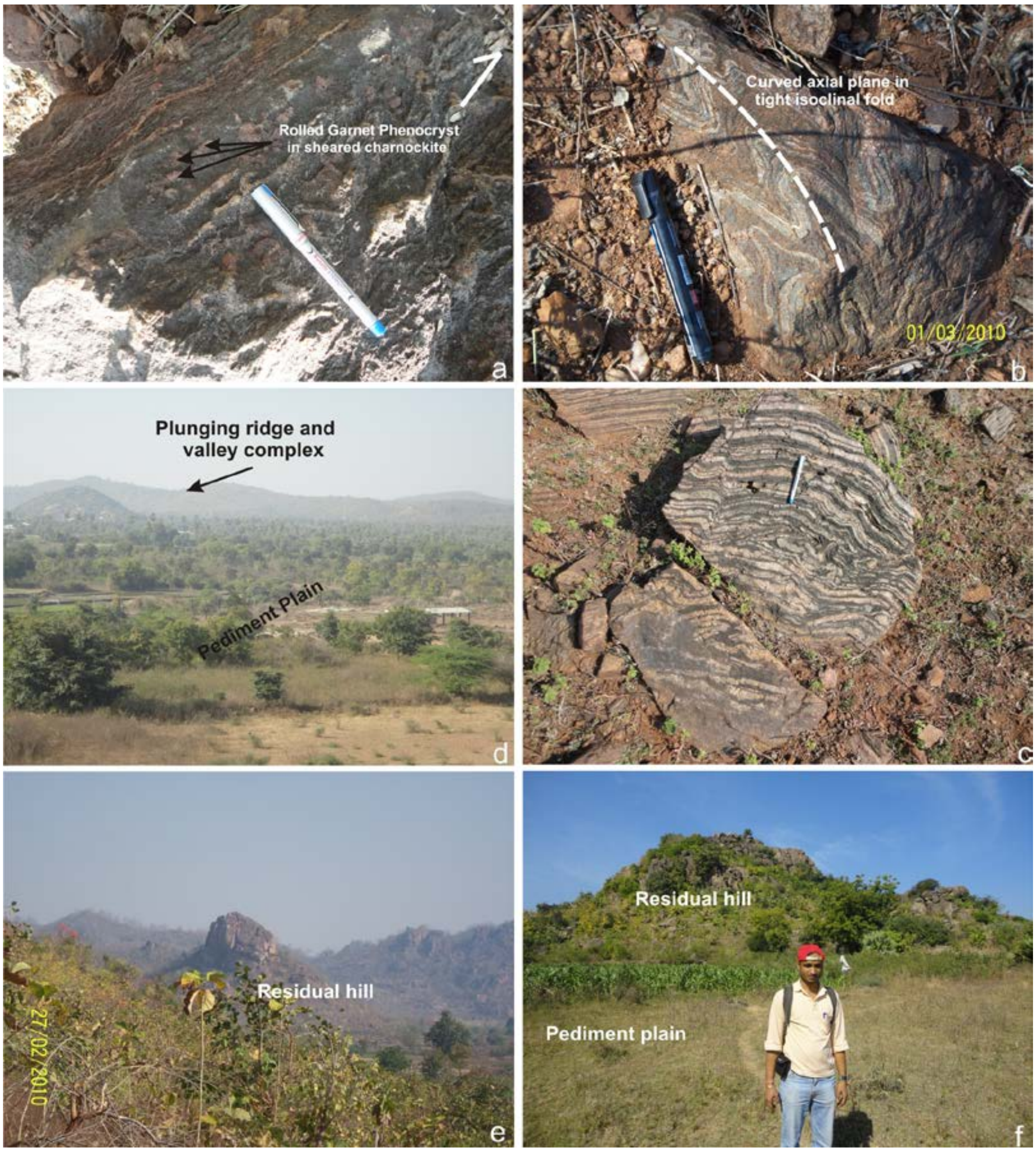

FIG. 5 Field photograph showing: (a) Rolled garnet porphyroblast (shear sense indicator and strain marker) embaded in sheared charnockites; (b) Tight isoclinal fold in banded magnetite quarzite with curved axial plain; (c) Tight isoclinal fold in banded magnetite quarzite with curved axial plain and refolded limbs; (d) Plunging ridge and valley complex with adjacent pediment plain; (e) Residual hills of granite gneisses near Kalleda and; (f) Residual hills with adjacent pediment plain near Yelgonda

trending ridge pattern is also common in northern sedimentary terrain of the area. Ridges are characterized with steep south facing slopes (scarps) and gently sloping northern sides. These linear ridges are separated by narrow flat valleys and show lateral dislocation alluding to the presence of ENE-WSW trending strike slip faults. In southern part of the study area near Sriramulapalle and Raghavpatnam however, the trend of ridges and valleys are NE-SW. Several dolerite dykes striking NE-SW[26-27], and F_1 phase of folding deduced in the present study signify the presence of ENE-WSW trending lineaments. Deeply penetrating weak zones might have provided easy accesses for the emplacement of magma generating numerous dykes. Therefore, major lineaments trending in the NNW-SSE and ENE-WSW direction are apparent.

Since the sedimentary terrain is quite younger than the adjacent metamorphic terrain, it seems that at least later folding episode (F_2 folds) has affected both metamorphic and their supracrustal sedimentary cover. Further detail structural analysis of adjacent sedimentary terrain and their correlation with present structural findings may conclusively establish the chronostratigrapy of the tectonic episodes within a larger area.

In a ridge-valley system, residual hills sometimes standing out prominently in isolation as well are invariable associated with sloping rocky and gravelly pediment plains (Fig. 5e, f). These pediment surfaces are the result of weathering and mass wasting events by virtue of gravity sliding. Dislodged rock material is readily fans out from hill slopes towards the

valleys. These loose gravelly deposits are often silted and mud-supported indicating emplacement as debris flows for which fine-grained clay is provided by the decay of phyllosilicates available in abundance in metamorphic rocks. Sometimes fluvial and aeolian processes may also effectively sort out and redistribute the material forming flat valley floors (Fig. 4b). In general, these pediments are covered with a thin veneer of fine to coarse clastics showing decreasing grain size trends away from hill slopes towards the valleys. These pediments also have a thin lateritic veneer of soil formed under well drained humid conditions.

The dominance of radial pattern of drainages at places (Fig. 3) is due to residual hills in the area. Parallel steams joining the higher order streams at right angle are also common feature of drainage geomorphology. This parallelism in streams seems related to presence of numerous joints and subsidiary faults running parallel or angles to major lineaments trends (Fig. 5).

Results

Precambrain Pennisular Craton is considered old, cold and rigid without much tectonic disturbance since Upper Proterozoic. The most stupendous tectonic activity that rocked the Eastern Dharwar Craton (EDC) took place at about 2.5 Ga ago when Madurai Block collided with the Dharwar Craton and subducted below it along roughly E-W running Palghat-Cauvery Shear Zone[28-29]. This compressive tectonics greatly affected both the colliding blocks generating a network of faults and shear planes. Workers have shown some well-defined structural trends related either to compression or associated with extensional blocks during different time periods[30-32]. Two well defined and known NNW-SSE and ENE-WSW lineament trends are prominently represented in the imageries and DTM of the area. Along these lineaments the ridges are characterized with steep south facing slopes (scarps) and gently sloping northern sides. These structural dispositions in all the probability entail reverse faulting.

Additionally a few strike slip faults aligned ENE-WSW are also visible offsetting the above mentioned lineaments and ridges. Our study based on field based structural analyses, GIS based DTM analyses, events are generally not related to major lineaments that have created large-scale folding; rather these are the result of compressive accumulating forces due to and remote sensing evidences demonstrate that Narella area of Andhra Pradesh suffered multiple deformation affecting both Precambrian metamorphic basement as well as upper Proterozoic to Paleozoic sedimentary cover. At least two episodes of tectonic reactivation of lineaments are documented, and they seem to have played a commanding role in shaping topography and structural style of the area. The intersection of NNW-SSE and ENE-WSW trending lineaments have had caused multiphase folding, dyke emplacement, residual hills and weak zones marked by extensive crushing and deformation of rocks. The older F_1 folding event that has deformed the basement metamorphics only may be related to 2.5Ga event when the two crustal blocks collided. However, NNW-SSE trending F_2 generation folds affecting metamorphics as well as younger sedimentary cover were separated from the metamorphic by a well-defined Eparchean. Unconformity seems a later event that took place at about 1.8Ga[20], much after the F_1 folds confined only to basement metamorphics were formed. Dolerite dyke swarms aligned NE-SW also testifies reactivation of deep facilitating magma intrusion. Ridge and valley topography formed as a consequence of repeated folding of the rock strata strictly follows the lineament trends. However, cross-cutting trends of ridges incorporating isolated hillocks and angular valley shapes may be related to activity along interacting lineaments and strike slip faults. Formation of pediment surfaces and gravel deposits, exceptionally straight and parallel courses of major rivers and radial pattern associated with residual hills point to a tectonic control exerted by folding, faulting and related fractures on the drainage of the area. Rocky pediments covered with loose clastic material ranging in size from gravel to silt-clay imply effective reworking by streams and aeolian processes. Lateritic cover on the pediment surfaces suggests a phase of tectonic quiescence in the area in millennial scale and the processes of pedogenesis under stable well drained sub-humid-monsoonal conditions.

Never the less, Hyderabad and adjoining areas have experienced stray seismic activities in the recent past. Two such earthquakes events, one in October 1876 having the intensity of 6[33], followed by the second in 16 September 2000 having the magnitude of 2.8 were instrumentally recorded and felt by the common man. In intraplate regions of south India, such earthquake interaction of Indian plates against the Asian Plate[34]. The accumulating stresses may induce reactivation of existing faults and that can cause recurring seismicity.

Present study documenting the tectonic control on drainage, steep exposed scarp faces and multiphase deformation of country rocks alludes to rejuvenation of geomorphic setting of the area and that may be related to incipient deformation of rocks under accumulating stresses.

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Since last 10 years, he is actively associated with structure-tectonic and metamorphic petrology and pursuing his research work in collaboration with faculty members of the Department of Geology, Banaras Hindu University, Varanasi, India. He has proved his expertise in deciphering tectonic history of metamorphic and sedimentary rocks of different geological terrains of Central India, Southern India and North-Eastern Himalaya. He has attended several workshop/symposia on Remote Sensing and GIS application in different parts of India. He has also attended seminar on “Shear Zone” in Department of Geology, Banaras Hindu University, Varanasi, India in 2007. Presently he is serving as Assistant Professor in Department of Earth Science, Bahir Dar University, Ethiopia. Currently, he is actively involved in deciphering the tectonic history of inverted metamorphic terrain of Darjeeling Himalaya.

Dr. Singh has got CSIR- NET award in 2003 as well as UGC RFSMS award in 2009. He has some significant international publications including Journals such as Quaternary International, Geological Society of India, Indian Society of Remote Sensing and International Journal of Remote Sensing Applications etc.

Prof. Uma Kant Shukla received his B.Sc. and M.Sc. degree in Geology from Lucknow University, Uttar Pradesh, India. He has received his Doctorate degree (Ph.D.) from the same University in 1992. He has successfully completed Fast track research project sponsored by DST.

Since last 22 years, he is actively associated with sedimentology and pursuing his research work in collaboration with national and international earth scientists. His research work is mainly confined on sedimentological evolution of Mesozoic and Proterozoic sequences of the Kachchh Basin and Lesser Himalaya respectively, Investigation of Quaternary inter-and-intramontane lake deposits of Ladakh and Kumaun Himalaya for tectono-climatic changes, Neogene Siwalik and modern Gangetic Foreland Basin sediments have been studied to generate facies models for various depositional domains in response to modern fluvial processes; and to evaluate the role of synsedimentary tectonism and palaeoclimate influencing the mode of sedimentation and modern fluvial processes. He has attended several workshop/symposia in India and abroad. Presently he is serving as Professor in Department of Geology, Banaras Hindu University, Varanasi, India.

Prof. Shukla has been awarded Alexander von Humboldt Fellowship (Germany). He has many significant national and international publications.

Praveen Chandra Singh received his B.Sc. (Hons.) in 2007 and M.Sc. degree in Geology in 2009 from Banaras Hindu University, Varanasi, India. He is pursuing his Ph.D. in Metamorphic Petrology from the same University. He has worked in research oriented project on Granulites of southern India sponsored by Department of Science and Technology, Government of India.

Since 2009, he is actively associated with metamorphic petrology and pursuing his research work under supervision of Dr. Divya Prakash. He has proved his expertise in metamorphic petrology through pseudosection modeling to extricate the P-T path of Precambrian metamorphic terrains of India. He has attended the remote sensing workshop in Institute of Technology, BHU, India and Pseudosection modeling through THERMOCALC workshop in Institute of Technology, Kharagpur, India.

Mr. Singh has got CSIR- NET award in 2009 as well as UGC RFSMS award in 2010. He has some significant publications including Journal of Asian Earth Science and International Journal of Remote Sensing Applications etc.